Traffic Forecast Impact on Spectrum Fragmentation in Gridless Optical Networks

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Abstract Gridless Technology increases the spectral efficiency of optical fiber transmissions, introducing however spectrum fragmentation. In this work, we show that traffic forecast permits to avoid spectrum fragmentation, even with an uncertainty of 10% on the growth rate.

Introduction
Conventional fixed grid optical networks are characterized by an inefficient use of the spectrum resources as fixed channel spacing must be used, even if the required spectrum amount is smaller. Gridless technology addresses this issue by introducing a flexible grid (frequency slots with a spectrum width of 12.5 GHz). Several contiguous frequency slots can be gathered to better match the required and the allocated spectra. However, this creates heterogeneous sizes of blocks of slots causing Spectrum Fragmentation (SF). The spectrum contiguity constraint becomes thus more difficult to satisfy increasing the bandwidth blocking probability.

In the literature several methods have been proposed to solve or mitigate the SF. The simplest method consists to avoid SF by specifying how a given demand request should be routed. When bandwidth blocking occurs, other intuitive approaches consist to split the demand into sub-demands, in such a way that the demand is unblocked. Some spectrum defragmentation heuristics have been proposed for transparent and translucent optical networks. Although these methods allow to mitigate fragmentation or to accommodate to the situation, they either remain limited or not easy to be implemented and thus do not offer an efficient solution to the problem.

In this paper, we propose to use traffic forecast strategies to address the fragmentation issue. Results show that traffic forecast is an efficient method even in case of significant errors in the forecasted traffic values.

Traffic forecast
While the traffic engineering is defined as "to put the traffic where the bandwidth is", network planning through traffic forecasts consists to "put the bandwidth where the traffic is forecasted to be". In this way, some optimization processes can be performed in advance and traffic dynamicity causing SF can be kept down. However, since a perfect knowledge of future traffic is not possible, the uncertainty in traffic forecast represents a major issue. Indeed, when the uncertainty in traffic forecast is introduced in the network planning, a trade-off between the robustness and the overdimensioning cost is required.

In conventional core optical networks, traffic behavior is less fluctuating and it continually grows in an incremental way. Therefore, an incremental model, in which only discrete intervals (periods of time) are considered, is more appropriate. In incremental traffic scenarios, a new traffic matrix is computed at the beginning of each period and possible errors in the traffic forecast are taken into account. For short periods (6-12 months) the impact of these errors can be mitigated using, for example, traffic rerouting strategies.

In this work, we model the uncertainty in the traffic forecast as a random additional variable (randomly drawn for every new demand) not exceeding a tunable uncertainty level $\beta$ added to the pre-defined annual growth rate $\alpha$. Furthermore, considering the fact that SF is strongly dependant on link occupancy, we evaluate the worst case where the optical network is under-dimensionalized ($\beta \geq 0$).

Network model
We consider the transponder model, summarized in Tab. 1, proposed in. Transponders and superchannels are characterized by bitrates, ranging from 100 Gb/s single channel to 1 Tb/s superchannel, and by maximum reaches. The spectrum occupancy (granularity) is defined as a multiple of 12.5 GHz frequency slots. The relative cost of a transponder is given as a function of the 100 Gb/S QPSK transponder cost. The cost of a superchannel is calculated according to the cost of its individual transponders. We consider successive upgrade periods of one year. Demands are optimally served selecting the set of transponders (with regenerator placement) that minimizes in a hierarchical way the cost and the spectrum occupancy. At the beginning of
each period, the existing resources are kept without any alteration (this is an operational constraint).

We evaluate the following provisioning scenarios using a k-shortest path routing and a first-fit provisioning policy. When the first blocking occurs dimensioning process is stopped and only periods that have been satisfied in all scenarios are considered. 

**Fixed grid scenario:** It is used as a reference for the other scenarios and can only select 4-slot-based transponders.

**Gridless scenario:** In gridless network, the planning process can choose any kind of transponders provided that the spectrum contiguity constraint is respected.

**Forecast gridless scenario:** It is an all-period forecasting gridless strategy that anticipates traffic growth and serves all demands in one period. When uncertainty is considered ($\beta \neq 0$) an additional volume of traffic must be considered at the end of the dimensioning. Please note that traffic forecast is equivalent to an active defragmentation process with adaptive rerouting and it does not have the operational constraint above since traffic forecast is an all-period strategy.

To quantify SF, we use Access Blocking Probability metric (ABP) defined as in Eq. (1).

$\text{ABP} = 1 - \frac{\sum \text{All_Free_Slots} \cdot \text{DIV} \cdot g_k}{\sum \text{f}_i \cdot g_k}$

Where $f_i$ denotes the free fragment number $i$ of the fiber, $\{g_1, g_2, g_3 \ldots\}$ is the set of granularities (Tab. 1), and DIV depicts the integer division.

The main concern of this metric is that it deals with transponder granularities to evaluate the created blocks of slots. Thus, the more a block does not match these granularities; the closer is its ABP value to one (100%).

**Results**

Simulations are performed on the transcontinental European backbone network detailed in Tab. 2. Considering an exponential yearly growth rate $\alpha = 30\%$, thirty traffic matrices initially normalized to 6 Tbps have been randomly generated according to an arbitrary tree logical topology. We assume 360 frequency slots per fiber in the C-band (4.5 THz) and one fiber pair per link.

Fig. 1 gives statistics about used transponders (superchannels) for both gridless (in the last period) and forecast gridless scenarios. Transponders are represented in the form of bitrate/granularity/reach. The first two sets are respectively 3-slot and 4-slot based transponders; the latter set items are all superchannels. By forecasting, the number of 4-slot-based transponders is remarkably reduced and new superchannels appear which impacts both the cost and the spectrum use. This is due to the fact that when current and future demands are jointly served a part of spectrum is saved thanks to superchannels solutions.

For different forecast period durations and different traffic volumes, Fig. 2 shows the evolution of saved spectrum percentage compared to conventional fixed grid provisioning. Using a 95% confidence interval, the spectrum gain does not exceed 15% for gridless scenario as significant parts of optimally selected transponders are 4-slot-based solutions (shown in Fig. 1). Accordingly, traffic forecast permits to improve this gain using additional superchannels solutions which are a trade-off between reach and spectrum occupancy without any impact on the overall cost. That is why forecast gridless scenario is considered at most as expensive as gridless scenario.

Fig. 3 presents the SF level after six years for different scenarios using ABP metric. Considering an exact forecast, SF issue is almost solved (ABP is around 5%). The residual fragmentation is unavoidable because of spectrum continuity constraint and then it can only be solved with wavelength converters (not considered here).

Moreover, if we consider 10% of uncertainty on

**Table 1:** Characteristics of Transponders

<table>
<thead>
<tr>
<th>Bitrate (Gbps)</th>
<th>Modulation Format (all SDFEC)</th>
<th>Baudrate (Gbaud)</th>
<th>Granularity (slot)</th>
<th>Reach (km)</th>
<th>Cost (a.u.)</th>
<th>Bitrate (Gbps)</th>
<th>Modulation Format (all SDFEC)</th>
<th>Baudrate (Gbaud)</th>
<th>Granularity (slot)</th>
<th>Reach (km)</th>
<th>Cost (a.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>16QAM</td>
<td>16</td>
<td>3</td>
<td>400</td>
<td>0.7</td>
<td>200</td>
<td>2xQPSK</td>
<td>2x32</td>
<td>7</td>
<td>1900</td>
<td>2</td>
</tr>
<tr>
<td>100</td>
<td>16QAM</td>
<td>16</td>
<td>4</td>
<td>400</td>
<td>0.7</td>
<td>400</td>
<td>2x16QAM</td>
<td>2x32</td>
<td>7</td>
<td>400</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>QPSK</td>
<td>32</td>
<td>3</td>
<td>1400</td>
<td>1</td>
<td>400</td>
<td>4xQPSK</td>
<td>4x32</td>
<td>13</td>
<td>1900</td>
<td>4</td>
</tr>
<tr>
<td>100</td>
<td>QPSK</td>
<td>32</td>
<td>4</td>
<td>2100</td>
<td>1</td>
<td>1000</td>
<td>5x16QAM</td>
<td>5x32</td>
<td>16</td>
<td>400</td>
<td>5</td>
</tr>
<tr>
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<td>3</td>
<td>300</td>
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<td>1000</td>
<td>10xQPSK</td>
<td>10x32</td>
<td>31</td>
<td>1900</td>
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<tr>
<td>200</td>
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<td>10x32</td>
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<td>10</td>
</tr>
</tbody>
</table>

**Table 2:** The Network characteristics

<table>
<thead>
<tr>
<th>Number of links</th>
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<tbody>
<tr>
<td>Number of nodes</td>
<td>32</td>
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<tr>
<td>Link length (km)</td>
<td></td>
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<tr>
<td>Min</td>
<td>10</td>
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<tr>
<td>Mean</td>
<td>280</td>
</tr>
<tr>
<td>Max</td>
<td>930</td>
</tr>
</tbody>
</table>
the yearly traffic growth rate, results in Fig. 3 and Fig. 4 show that SF remains limited and does not reach the values of gridless incremental scenario. This allows to go on getting benefit from superchannel solutions that are more subjected to bandwidth blocking.

Note that 10% of uncertainty is considered significant in core networks compared to the growth rate (α = 30%) and it gives rise to large absolute uncertainty due to exponentional growth.

Indeed, serving jointly an important traffic volume is always better in terms of the contiguity of used spectrum and then its fragmentation.

**Conclusions**

In this paper, we have evaluated traffic forecast in gridless networks to solve SF issue. Simulation results show that traffic forecast is a successful active, hitless and costless strategy that allows to avoid spectrum fragmentation. It also permits to spare spectrum since it favors superchannel solutions.

Another interesting result is that even with 10% of forecast uncertainty on traffic growth rate the SF remains lower compared to the gridless incremental scenario.

Making the best of gridless requires smarter processes than simple first-fit provisioning. Traffic forecast is a robust method to alleviate fragmentation level and avoid inconvenient defragmentation approaches. However, with dynamic traffic behavior, traffic forecast can be subjected to internal fragmentation when some traffic demands vanish.

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**References**


